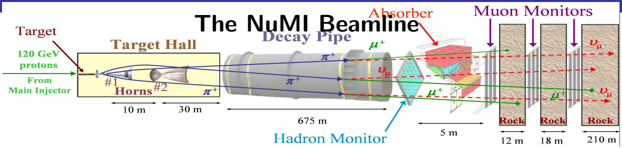
LBNE Physics and Beam Designs

DOE Underground Science Review, SLAC 4/14/11

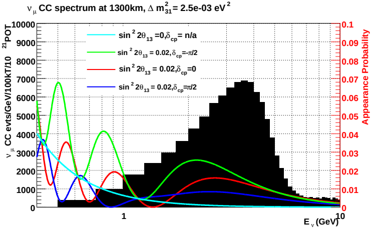
Mary Bishai (BNL)

April 13, 2011

Requirements of the FNAL/Homestake Beam



The design specifications of a new WBLE beam based at the Fermilab MI are driven by the physics of $\nu_\mu \longrightarrow \nu_e$ oscillations:



L = 1300 km, Normal Hierarchy

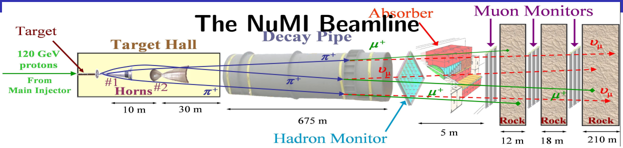
Requirements:

-Maximal possible neutrino fluxes to encompass the 1st and 2nd oscillation nodes, with maxima at 2.4 and 0.8 GeV.

-High purity ν_μ beam with negligible ν_e

-Minimize the neutral-current feed-down contamination at lower energy, therefore minimizing the flux of neutrinos with energies greater than 5 GeV is highly desirable.

Requirements of the FNAL/Homestake Beam



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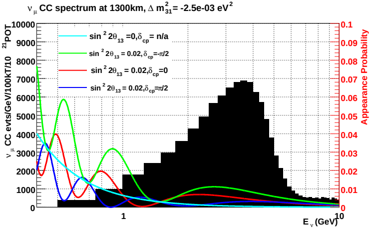


L = 1300 km, Inverted Hierarchy

Requirements:

-**Maximal possible neutrino fluxes** to encompass the 1st and 2nd oscillation nodes, with maxima **at 2.4 and 0.8 GeV**.

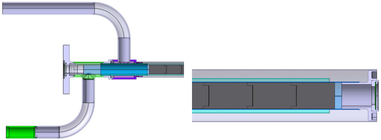
-**High purity ν_μ beam** with negligible ν_e

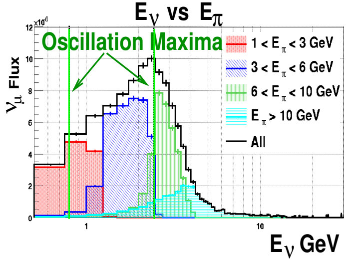
-Minimize the neutral-current feed-down contamination at lower energy, therefore **minimizing the flux** of neutrinos with energies **greater than 5 GeV** is highly desirable.

LBNE Target Design

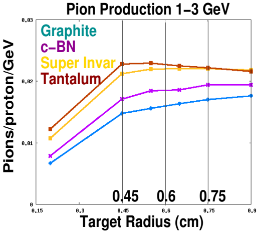
The designed LBNE target is a cylindrical segmented graphite tube. r=0.765cm, l=95cm (2 interaction lengths) long. Water cooled.

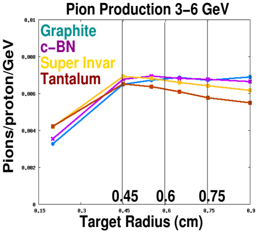
Target design from IHEP

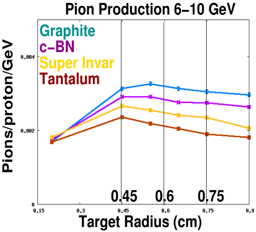




π production study by Y. Lu:



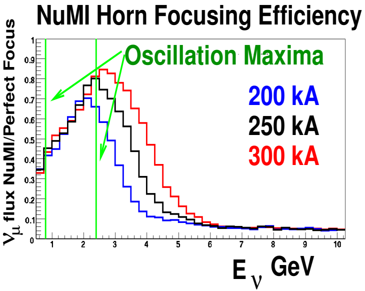


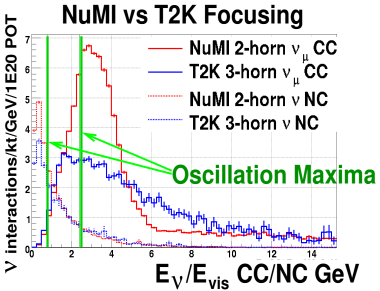


C target at 120 GeV is optimal for ν production at the 1st maximum

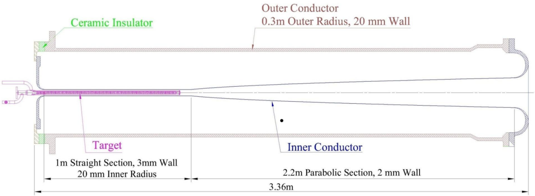
The Focusing System for LBNE

A focusing system with the 2 NuMI horns with an embedded cylindrical graphite target, is well suited for LBNE:



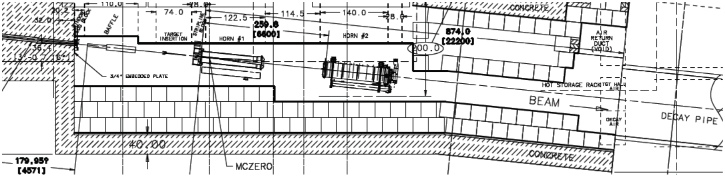


Modifications to NuMI horn 1 in technical design (Y. He, B. Lundberg, FNAL)**:**

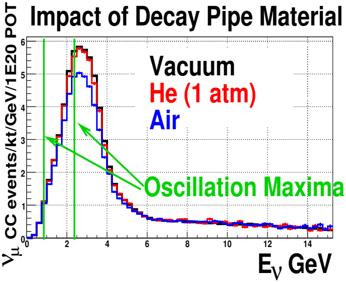


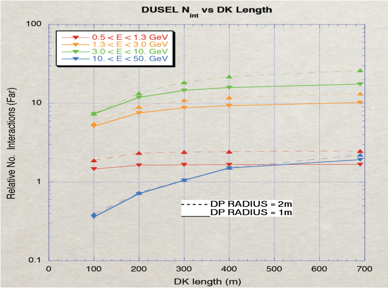
LBNE Physics and Beam Designs
Mary Bishai (BNL)
Specifications
Target/Horn designs
Beamline Geometry/Material
Physics Sensitivities
Primary Beam Energy
Possible Beam Design Improvements
Summary and Conclusions

Beamline Geometry/Material



Air cooled decay pipe with radius=2m, length = 200 to 250m

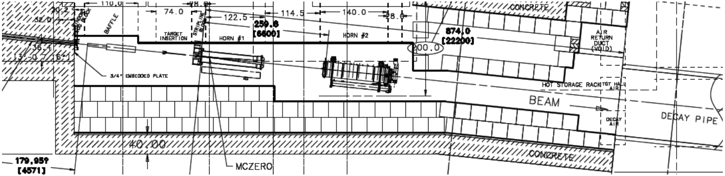




He vs Air filled DP

Impact of DP radius/length.

Beamline Geometry/Material



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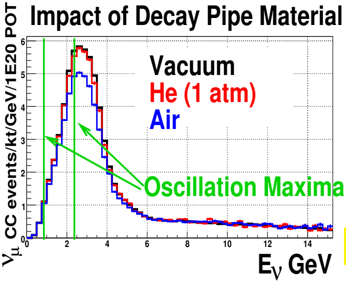


He vs Air filled DP

D.P. length m	Rate 0-2 GeV	Rate 2-6 GeV	Rate > 6 GeV
180	3.1	11	6.3
280	3.5	14	8.1
380	3.6	16	9.7
480	3.7	17	11
580	3.7	17	11

Decrease DP length from 250 to 200 m

$\sim$ 13% decrease in rate at 1300km

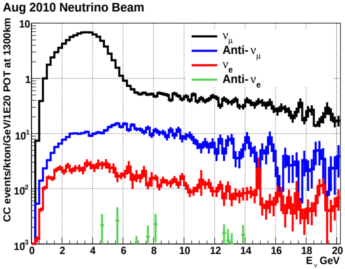
The LBNE Beam Design for Case Studies

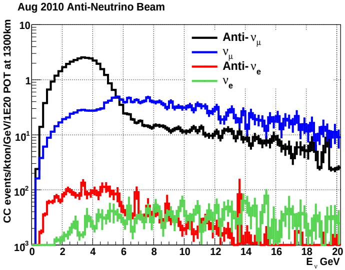
The LBNE design selected for physics studies maximizes the ν_e appearance signal at 1300km.

Target: **Carbon target, r=0.6cm, l=80cm, $\rho = 2.1$ g/cm^3. Located -30cm from Horn1.**

Horns: **2 Al NuMI Horns, 6m apart, 250 kA.**

Decay Pipe: **r=2m, l=280m, He filled/evacuated.**



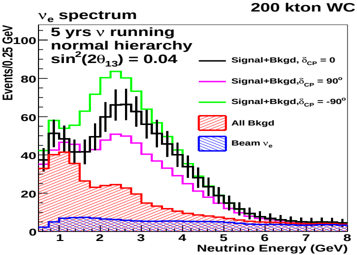


Oscillation CC rates/(100 kT.MW.yr) in $0.5 < E_\nu < 20$ GeV:

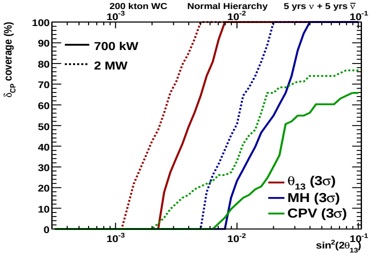
ν beam, $\Delta m^2_{31} = +2.5 \times 10^{-3}\mathrm{eV}^2$, $\delta_{cp} = 0$, $\sin^2 2\theta_{13} = 0.04$

Beam Tune	ν_μ	ν_μ osc	ν_e beam	$\nu_\mu \to \nu_e$	$\nu_\mu \to \nu_\tau$
Low-Energy (LE)	29K	11K	260	560	140

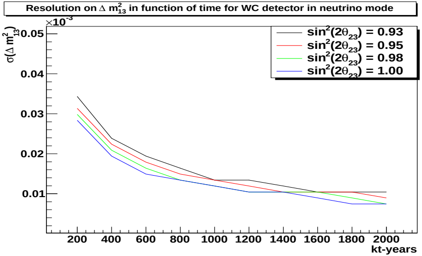
LBNE Physics from WCD Case Study



Large ν_e signal above bkgd



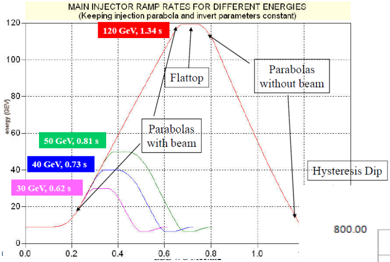
2 MW beam improves physics reach



0.6% resolution on Δm^2_{32} in 5 yrs with 700kW

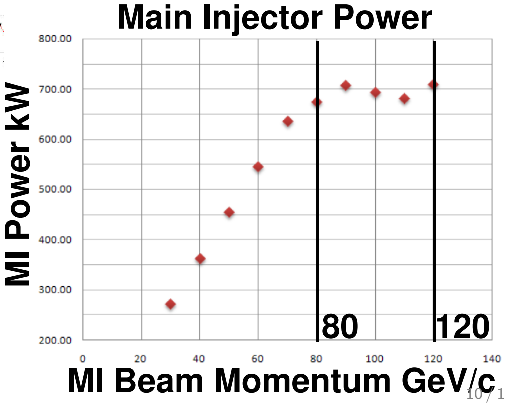
Main Injector Proton Beam Power

R. Zwaska, FNAL



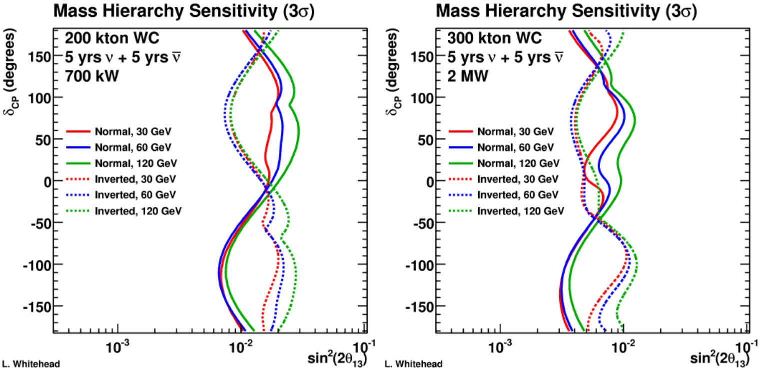
⟵ **The FNAL Main Injector ramp**

NEW: From V. Papadimitriou Jan 2011 ⟶



Impact of Primary Beam Energy

Sensitivity to Mass Hierarchy at 3σ



Sensitivity at δ=0, normal hierarchy

	30 GeV	60 GeV	120 GeV
200 kton, 700 kW	0.0158	0.0178	0.0200
300 kton, 2 MW	0.0050	0.0071	0.0100

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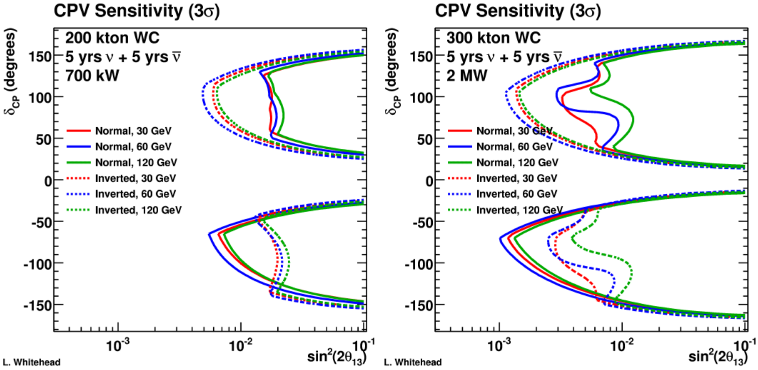
MI may be able to deliver 700kW from 80-120 GeV only

Impact of Primary Beam Energy

Sensitivity to CPV at 3σ



Maximum sensitivity, normal hierarchy

	30 GeV	60 GeV	120 GeV
200 kton, 700 kW	0.0063	0.0056	0.0071
300 kton, 2 MW	0.0013	0.0011	0.0014

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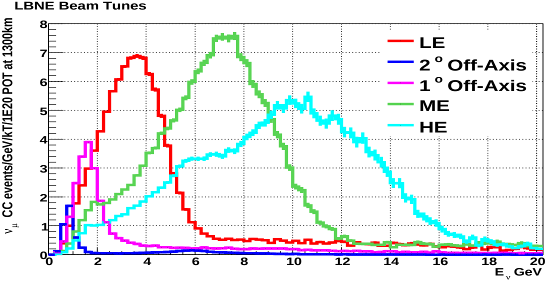
MI may be able to deliver 700kW from 80-120 GeV only

Tunable Beams for More Physics

Different beam tunes improve sensitivity to a wide range of physics:



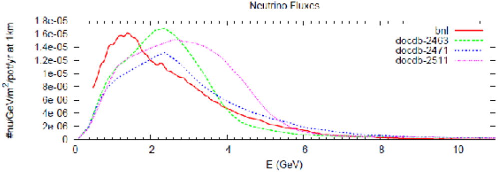
Oscillation CC rates/(100 kT.MW.yr) $0.5 < E_\nu < 20$ GeV:

ν beam, $\Delta m^2_{31} = +2.5 \times 10^{-3}\,\mathrm{eV}^2$, $\delta_{cp} = 0$, $\sin^2 2\theta_{13} = 0.04$

Target position	ν_μ	ν_μ osc	ν_e beam	$\nu_\mu \to \nu_e$	$\nu_\mu \to \nu_\tau$
-0.3m (1° OA)	8.0K	4.5K	120	110	37
-0.3m (LE)	29K	11K	260	560	140
-1.5m (ME)	44K	28K	320	480	640
-2.5m (HE)	47K	35K	280	340	800

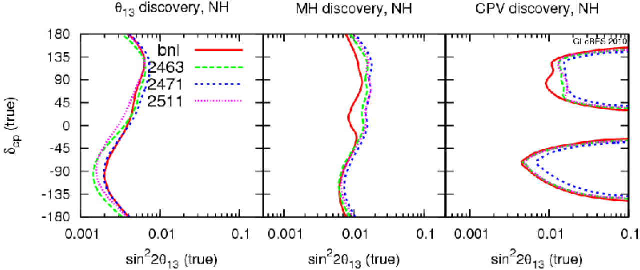
Impact of the 2nd Maximum

Different Beam Fluxes Studied



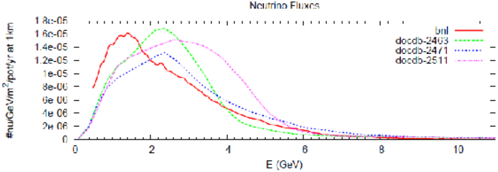
Impact of Second Maximum with Different Fluxes

$0.5 < E_\nu < 12$ GeV



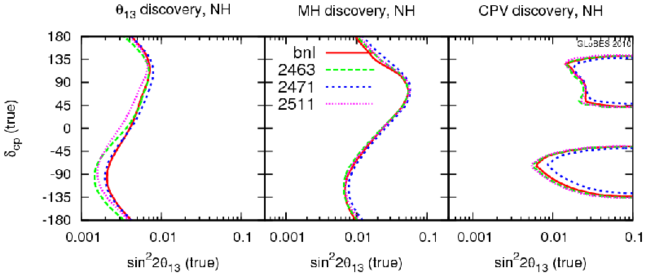
Impact of the 2nd Maximum

Different Beam Fluxes Studied



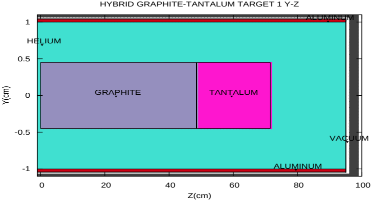
Impact of Second Maximum with Different Fluxes

$1.25 < E_\nu < 12$ GeV

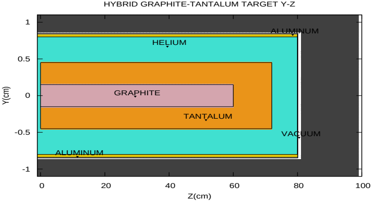


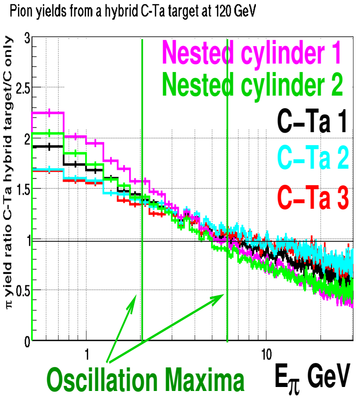
Hybrid target design: NEW

C-Ta Design



Nested-cylinder Design

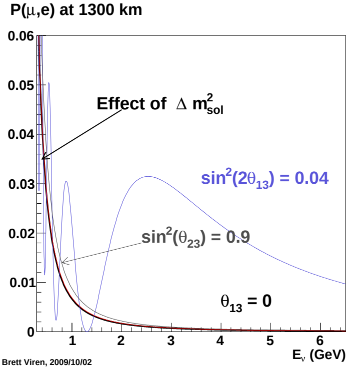


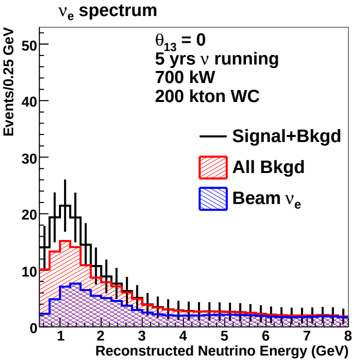


Increases π flux at 2nd maximum by $\sim$ 50%

Decreases π flux $>$ 20 GeV ($E_\nu > 8$ GeV) by 50%

Improves access to θ_{23} octant, exclusive measurement of ν_e appearance when $\theta_{13} = 0$ and more clean flux at 2nd maximum. These beams could be generated by moving the beam focusing 1° off-axis, or with a multi-MW 5-8 GeV beam (Project X ?).





Physics impact is still being assessed.

Summary and Conclusions

- **The techical design of the LBNE beamline is very advanced and relies heavily on the experience from NuMI.**
- **There is still a lot of room for improvement.**
  Lots of bang for few bucks in improving target/focusing designs.
- **Reducing the decay pipe length reduces the flux - more running time to get the same physics. An air filled decay pipe also reduces the flux further (15% at the 1st osc maximum).**
- **At least 2 beam tunes are needed to constrain near to far extrapolation. Tunable beams = more physics.**
- **Physics with low energy long baseline beams is being studied.**